# AN EXPERIMENTAL STUDY OF HENNING'S SYSTEM OF OLFACTORY QUALITIES[1]

By Malcolm K. Macdonald, University of Pennsylvania

The purpose of this study was the verification of the qualitative olfactory continuum represented by Henning's[2] smell prism. We hoped either to verify the general nature of the continuum or to discover necessary modifications of it. As secondary matters we hoped that we might be able to specify a practical set of stimuli for the demonstration of the prism and, by using stimuli of known chemical nature where possible, to obtain some incidental information bearing upon Henning's theory of the chemistry of the olfactory stimulus.

Henning represents the odors as lying in a qualitative continuum represented by the surface of a triangular prism.[3] At the six corners of this prism are the six principal groups of odors, which correspond to the *Hauptfarben* of the color pyramid as fundamental points of reference. At the corners of one triangular face of the prism lie the fragrant (F), ethereal (E), and putrid (P) odors, and at the other end respectively opposite these three are the spicy (S), resinous (R), and burned (B) odors. Along the edges and in the five faces lie psychologically simple and qualitatively intermediate odors, but the interior of the prism is hollow.

It will be convenient if we designate the principal odors at the corners as *simplex* odors. Such odors are the points of reference for the rest of the figure; they are fundamental and cannot be described qualitatively, whereas the other odors can be described by reference to them. Odors lying along an edge may be called *duplex* for the reason that they can be described by their qualitative similarity to two simplex odors. They are of course simple and not complex, but are defined in the qualitative system in a duplex manner. They may be designated as FE, EP, PF, SR, RB, BS, FS, ER, or PB. Within the faces there would be *multiplex* odors. At the middle of the rectangular sides (Henning's *Quadrupelpunkte*[4]) the multiplex odors are quadruplex: FESR, EPRB, and FPSB. In strict logic there should be no triplex odors in the rectangular sides, since any odor here should have fourfold similarity. Henning, however, appears at times to consider that odors near one corner and remote from the diagonal are practically triplex: dehydrocamphylcarbinol appears to be FSR[5].

[1]From the Psychological Laboratory of Clark University. Communicated by Edwin G. Boring.

[2]H. Henning, *Der Geruch*, Leipzig, 1916, pp. 533. Reprinted from the *Z. f. Psychol.*, 1915, 73, 161-257(=pp. 1-97 of *Der Geruch*); 1916, 74, 305-443 (=pp. 98-226); 1916, 75, 177-230 (=pp. 227-280); 1916, 76, 1-27 (=pp. 281-407). *Cf.* E. A. McC. Gamble, *Psychol. Bull.*, 1916, 13, 135 ff.; this Journal, 1921, 32, 290 ff.

[3]Henning, 80-97.

[4]Henning, 96, 299.

[5]Henning, 299.

The triangular ends should of course contain triplex odors, but Henning does not discuss these faces. This terminology is not Henning's, but is useful in representing his system.

Henning has a chemical theory[6] of the olfactory stimulus, which, if it held rigorously, would be a valuable aid in determining the stimuli for different regions of the prism. Odor, according to this theory, depends primarily upon the structure of the molecule of the stimulus, although it is also to some extent dependent upon the nature of the component elements.

The stimuli to the *simplex odors* have a single structural characteristic. The stimuli for the FESR face are all theoretically derivatives of the benzine ring. The PB line is characterized by the introduction of certain other elements as well as by molecular structure. The simplex stimuli are as follows.

*Fragrant.* An *ortho*-substitution product of the benzine ring, *i. e.*, substitution of chemical groups for the hydrogen at two adjacent corners of the six corners of the ring.

*Spicy.* A *para*-substitution product of the benzine ring, *i. e.*, substitution of chemical groups for hydrogen at two opposite corners of the ring.

Ortho-substitution and para-substitution are both forms of disubstitution. The only other disubstitution is meta-substitution, where the substitution is at the corners next but one. The meta-substitutions do not enter into the theory and should presumably be odorless. Monosubstitutions similarly do not appear in the theory. In a disubstitution product it makes no difference at which pair of corners the disubstitution occurs, provided only the spatial relation is fixed: all para-substitutions are identical for the same substituted groups, but different from ortho-substitution for the same substituted groups.

*Resinous.* An *inner* substitution in the benzine ring, *i. e.*, a disubstitution of a single group linking across between two corners of the ring and usually represented as within the ring.

*Ethereal.* A *hydrocarbon forked chain*, not necessarily related to the benzine ring, but discussed by Henning as if it belonged with the benzine derivatives. The theory is complicated at this point by the fact that there are few, if any, pure ethereal stimuli; nearly all are duplex ES and combine in the stimulus the fork with the para-substitution in the ring.

*Putrid.* *Forked chains* in which *sulphur*, *selenium*, *tellurium*, *nitrogen*, *phosphorus*, *arsenic*, *antimony*, *bismuth* are osmophores (smell producers; analogous to chromophores). Henning describes these forks as a disruption of the ring, but there seems to be no obvious chemical ground for this interpretation of a ring.

*Burned.* *Heterocyclic rings* including *nitrogen* with various numbers of sides. The benzine ring is homocyclic, since carbon is always the link, and it always has six sides. In a B stimulus nitrogen is substituted for carbon at one corner (not for hydrogen, as in the benzine derivatives).

The *duplex odors* have, on this theory, duplex stimuli, *i. e.*, stimuli that combine two of the simplex chemical characteristics. Thus in the FESR face they tend to be trisubstitution products. The stimulus to an FS odor combines the ortho-and para-substitution of the F and S groups. Such a ring is known as an asymmetrical ring. The stimulus to an SR odor combines inner and para-substitution; the FE stimulus should include a fork in one of the ortho-substitutions; and the ER stimulus should have a fork added to the inner substitution. There ought, on the theory, to be no FR odors which are not also E and S, and no ES odors which are not also F and R; and the corresponding duplex stimuli ought not to

[6]Henning, 281-305, esp. 291-301.

occur. Unfortunately for the theory, ES odors, as Henning admits, are the rule rather than the exception, and they are given by stimuli that add a fork to a para-substitution.

The duplex stimuli for the two faces which include the P and B corners are not well worked out by Henning, and the general principle of the theory cannot be extended here.

The faces should contain *quadruplex* stimuli, and possibly triplex stimuli, if there are any strictly triplex odors. The FESR face does contain both triplex and quadruplex stimuli. Thujone, the stimulus to the quadruplex odor at the center, illustrates the theory, for it is an asymmetrical ring (ortho- and para-substitution) with an additional inner substitution and with the para- connection carrying a fork.

The foregoing terms for the six principal olfactory groups have the advantage that they have different initials and provide a simple terminology for both simplex and multiplex odors (as do R, Y, G, O, RO, YG, *etc.*, for the colors). The usual English words and Henning's German which they translate are as follows.

F = Fragrant (flowery, *blumig, duftend*);
E = Ethereal (fruity, *früchtig*);
P = Putrid (foul, *faulig*);
S = Spicy (aromatic, *würzig, gewürzhaft*);
R = Resinous (piny, balsamy, *harzig, balsamisch*);
B = Burned (burning, scorched, empyreumatic, *brenzlich*).

## *Stimuli*[7]

We sought to select stimuli which should represent all parts of the prism and which have been definitely placed by Henning. In addition we sought, when possible, to choose stimuli of definite chemical composition in order that we might obtain some incidental information concerning Henning's theory of the stimulus, and also for the reason that such a stimulus is more definitely defined in nature than is a common object. The selection proved peculiarly difficult, because Henning skimps many parts of the prism in his lists of representative odors. In some regions, where Henning cites definite chemical examples, we were unable to obtain the stimuli. For example, we did not succeed in finding thujone (FESR), camphene (ER), cadaverine (PB), chavicol (S), cineol (R), or cajuputol (R), in this country or in England. The PB edge does not permit of laboratory investigation; Henning had to take his *O*s to the zoological gardens to obtain these odors.

Table I gives a list of the stimuli which were used at any time during the experiment. A more definite characterization of these stimuli, and a statement of the reason for the rejection of many, follow. After the name of each substance is given its position on the prism according to Henning and in parentheses the page-reference to the statement in *Der Geruch*. It will be observed that, of these 35 stimuli, 20 are chemicals and 15 objects.

[7]Our thanks are due to Dr. George F. White, Professor of Organic Chemistry at Clark University, for his assistance in the selection and procuring of our stimuli and in obtaining information concerning their chemical structure.

TABLE I

LIST OF STIMULI. Standards are given in italics. An asterisk indicates a stimulus of definite chemical structure.

| | | |
|---|---|---|
| 1 | F | *Ionone |
| 2 | E | *Acetic ether |
| 3 | FS | *Vanillin |
| 4 | FESR | *Menthol |
| 5 | PB | *Amyl alcohol |
| 6 | RB | Burned mastic |
| 7 | B | Tar |
| 8 | B | **Pyridine* |
| 9 | B | *Nicotine |
| 10 | P | *Carbon disulphide |
| 11 | ER | *Xylene |
| 12 | SB | Burned coffee |
| 13 | P | *Asparagine |
| 14 | S | *Anisol |
| 15 | P | **Thiophenol* |
| 16 | R | Frankincense |
| 17 | FPSB | Celery |
| 18 | S | Nutmeg |
| 19 | R | Balsam of Peru |
| 20 | FESR | Wormwood |
| 21 | EPRB | Grapefruit rind |
| 22 | EP | Rotten fruit |
| 23 | FPSB | Onion |
| 24 | F | *Oil of jasmine* |
| 25 | FS | Vanilla |
| 26 | FE | *Citronellol |
| 27 | R | **Eucalyptol* |
| 28 | FPSB | *Apiol |
| 29 | S | **Anethol* |
| 30 | FE | *Geraniol |
| 31 | E | **Citral* |
| 32 | FP | Rotten flowers |
| 33 | SR | Allspice |
| 34 | SR | *Myrtenol |
| 35 | R | *Pinene |

| | | |
|---|---|---|
| SIMPLEX STIMULI | | |
| F | 1 | *Ionone |
| | 24 | *Oil of jasmine* |
| E | 2 | *Acetic ether |
| | 31 | **Citral* |
| P | 10 | *Carbon disulphide |
| | 13 | *Asparagine |
| | 15 | **Thiophenol* |
| S | 14 | *Anisol |
| | 18 | Nutmeg |
| | 29 | **Anethol* |
| R | 16 | Frankincense |
| | 19 | Balsam of Peru |
| | 27 | **Eucalyptol* |
| | 35 | *Pinene |
| B | 7 | Tar |
| | 8 | **Pyridine* |
| | 9 | *Nicotine |
| DUPLEX STIMULI | | |
| FE | 26 | *Citronellol |
| | 30 | *Geraniol |
| EP | 22 | Rotten fruit |
| FP | 32 | Rotten flowers |
| SR | 33 | Allspice |
| | 34 | *Myrtenol |
| RB | 6 | Burned mastic |
| SB | 12 | Burned coffee |
| FS | 3 | *Vanillin |
| | 25 | Vanilla |
| ER | 11 | *Xylene |
| PB | 5 | *Amyl alcohol |
| MULTIPLEX STIMULI | | |
| FESR | 4 | *Menthol |
| | 20 | Wormwood |
| EPRB | 21 | Grapefruit rind |
| FPSB | 17 | Celery |
| | 23 | Onion |
| | 28 | *Apiol |

*Simplex Stimuli*

1. Ionone. Not mentioned by Henning. Synthetic violet; might be expected to belong to the F corner. It is a derivative of tetrahydro-benzine and a vicinal ring, which is equivalent to two ortho-substitutions, and thus may be said to accord with Henning's theory. Considered as a possible standard for the F corner, but rejected in favor of oil of jasmine which has a stronger odor. Used throughout the experiment.

24. Oil of jasmine. F. (H. 82) Used throughout the experiment as a standard for the F corner.

2. Acetic ether. E. (H. 83) Henning places all the ethers at this corner of the prism. Acetic ether involves the forked structure required by Henning's theory. Used throughout the experiment.

31. Citral. E. (H. 295) Used as a standard for the E corner throughout the experiment. It is an open chain with a fork, and readily condenses into a ring with para-substitution and a fork. Thus it approximately fits Henning's theory. Its structure would seem to imply that it should be ES (or FESR?) and not pure E. (*Cf.* no. 26.)

10. Carbon disulphide. P. (H. 301) Considered as a possible standard for the P corner, but rejected because its odor is said to be due to impurities. As an open chain involving sulphur it should, on Henning's theory, lie at the P corner. Used throughout Part I.

13. Asparagine. P. (H. 301) Occurs in the form of crystals as an open chain involving nitrogen. It had no perceptible odor for our *O*s, in spite of the fact that Henning gives it as typical of the P quality. The crystal was loaned us and we were not permitted to try dissolving it. Used only in the very first part of the experiment.

15. Thiophenol (*Merkaptane*). P. (H. 301) The aromatic mercaptan used was thiophenol. As a mono-substitution of a sulphur chain in benzine it is a proper P on Henning's theory. As obtained from the chemical laboratory it was so strong as quickly to permeate the whole room when the bottle was opened. The method hit upon was to hold an empty bottle over the mouth of the bottle containing thiophenol. In a few minutes enough of the stimulus had adhered to the inside of the bottle to last for some time, but the process had to be repeated often. Used throughout Part I as a standard for the P corner.

14. Anisol. S. (H. 292) A mono-substitution product of benzine; its para-derivatives Henning characterizes as S. In the shortened series it was eliminated in favor of nutmeg, which has a definitely spicy quality.

18. Nutmeg (*Muskat*). S. (H. 81) Whole nutmegs were grated as needed. Used throughout the experiment.

29. Anethol. S. (H. 292) Satisfactory S stimulus, and used as a standard for the S corner throughout the experiment. It is a para-substitution product as required by Henning's theory.

16. Frankincense (*Olibanum, Weihrauch*). R. (H. 84) Weak stimulus but strengthened by pulverizing. Used throughout the experiment.

19. Balsam of Peru. R. (H. 84) Eliminated because too weak a stimulus.

27. Eucalyptol. R. (H. 297, *cf.* 84) Satisfactory representative of the R corner and used as a standard for that corner. An inner ring as required by Henning's theory.

35. Pinene. R. (H. 297) A good chemical stimulus for the R corner. It accords with Henning's chemical theory, since it is an inner ring. Used throughout the experiment.

7. Tar. B. (H. 85) Coal tar was found to have only a faint odor, which was, however, strong enough when the tar was pulverized. Used throughout Part I.

8. Pyridine. B. (H. 85, 300) As pure pyridine was too strong, it was diluted with distilled water. Pyridine is a 'smooth' heterocyclic nitrogen

ring, and thus represents Henning's typical B both qualitatively and chemically. Hence it was used as a standard for the B corner throughout Part I.

9. Nicotine. B. (H. 300) Similar to pyridine both chemically and in Henning's qualitative classification. Hence should be satisfactory, but proved too weak to give good results. Used throughout Part I.

### *Duplex Stimuli*

26. Citronellol. FE. (H. 296) Eliminated in favor of geraniol (no. 30) in order to reduce the number of stimuli on the FE line. It is an open chain with a fork and readily condenses into a ring with para-substitution and a fork, which should presumably under Henning's theory make it ES (or FESR?) instead of FE.

30. Geraniol. FE. (H. 296) Satisfactory FE stimulus, and used throughout the experiment. It is an open chain with a fork and readily condenses into a ring with para-substitution and a fork. It is therefore like citronellol and raises, because of its chemistry, the same theoretical objection. (*Cf.* no. 26.)

22. Rotten fruit. EP. Not mentioned by Henning, although seemingly implied as an intermediate. Early eliminated, however, because even when very rotten it was mostly like E. Rotten apples and oranges were used. It was difficult to keep this stimulus constant.

32. Carrion flowers (*Aaspflanze*). FP. (H. 85) The carrion flower was not available, but we used decayed flowers. They were, however, open to the same objection as decayed fruit (*cf.* no. 22) and were therefore eliminated.

33. Allspice. SR. (*Cf.* H. 34) Ground allspice. Used throughout the experiment as presumably representative of the SR line.

34. Myrtenol. SR. (H. 298) According to Henning a good representative of the SR line since it combines the inner and para-substitutions in the benzine ring; other texts, however, cite it as an oil of uncertain composition. Used throughout the experiment.

6. Burned mastic (*brennendes Mastixharz*). RB. (H. 85) The mastic gum on being burned forms a solid mass which has no perceptible odor. Discarded as an impractical stimulus. At best its odor is very weak.

12. Burned coffee (*gebrannter Kaffee*). BS. (H. 85) This was an unsatisfactory stimulus, for coffee exposed soon loses its odor and burning or roasting does not renew it. Eliminated during the first series.

3. Vanillin. FS. (H. 83) An asymmetrical ring and thus in accordance with Henning's theory. Used throughout the experiment.

25. Vanilla. FS. (H. 83) Vanilla beans. In the later series vanilla was eliminated in favor of the chemical vanillin (no. 3) which has a definite composition.

11. Xylene. ER. (H. 85) A disubstitution of $CH_3$ for H in a benzine ring. Does not seem to fit the chemical theory. Used throughout the experiment.

5. Amyl alcohol. PB. (H. 85) An open chain alcohol (a hydrogen, carbon and oxygen compound) with a fork, and should therefore on Henning's theory lie at the E corner and not along this edge. Used throughout Part I.

### *Multiplex Stimuli*

4. Menthol. FESR. (H. 85) Henning places it between E and S, and it would seem, therefore, from the logic of the prism, to be also between F and R, although it is not given as a quadruplex stimulus (H. 96). Chemically, on Henning's theory, it should be a triplex (FES) stimulus, since it combines the para-(S), ortho-(F), and forked (E) structures. Used throughout the experiment.

20. Wormwood (*Wermutarten*). FESR. (H. 96) Unfortunately had to be eliminated because a very weak stimulus, although it is, according to Henning, the typical quadruplex stimulus of this face of the prism. Menthol (*v.* no. 4) is theoretically a representative of the interior of this face.

21. Grapefruit rind (*Pompelmusfrucht*). EPRB. (H. 96) Henning mentions grapefruit for the middle of the EPRB face. New rind had to be obtained frequently, as it decayed rapidly. Used throughout Part I.

17. Celery. FPSB. (H.85, 96) Celery seed. Celery according to Henning represents the quadruplex stimulus for this face of the prism. Used throughout Part I.

23. Onion. FPSB. (H. 85) Eliminated because celery (no. 17) represents the same place on the prism and is a more constant stimulus.

28. Apiol. FPSB. (H. 96) Satisfactory as a stimulus, and used throughout Part I. It is a complex penta-substitution product, apparently not related to Henning's chemistry of the prism.

*Procedure.* Henning insists on dirhinic smelling.[8] To ensure the use of both nostrils, 50 cc. glass-stopper, salt-mouth bottles (6.34 cm. deep, 2.54 cm. mouth-diameter) were used for presenting the stimuli. Henning also states that memory-smells, akin to memory-colors, fuse with the quality when the *Os* know the nature of the substances.[9] To pay regard to this admonition, the bottles were covered with paper and the *Os* were instructed not to look within. The different stimuli were identified by inconspicuous numbers on the covering of the bottles. The numbers had no relation to the position of the odors on the prism.

*Standards.* As a standard for the F-corner there was a choice among several of the essential perfume oils, oil of jasmine, oil of geranium, oil of ylang-ylang, and tonka bean, oppoponax, mimosa and coumarin. We selected *oil of jasmine*, which was of sufficient strength for a satisfactory standard, after rejecting the chemical ionone (*v. supra*).

For the E-corner there was a choice of the several ethereal oils, such as oil of lemon peel, oil of lime, oil of orange, as well as some of the ethers, *e. g.*, acetic ether. *Citral* was chosen as a standard on account of its known chemical nature as against the oils, and because it has a stronger and more distinct odor than the ethers.

For the P-corner there was the choice of carbon disulphide, hydrogen sulphide, the mercaptans, the cacodyls, and the stabines. Carbon disulphide was not used because its odor is said to be due merely to the presence of impurities. *Thiophenol*, one of the mercaptans, was selected because of its distinct strength of odor.

For the S-corner, from the ordinary spices and several chemicals, *anethol* was chosen on account of known chemical structure and availability.

*Eucalyptol* was chosen for the R-corner, from among frankincense, oil of cedarwood, tincture of myrrh, *etc.*, because of its known chemical structure.

From a number of chemicals at the B-corner, *pyridine* was chosen because sufficiently strong and easily available.

The standards thus selected were covered with paper, as were the other stimuli, but were prominently marked with large black gummed letters from I to N. These letters were chosen as having fewer associations than those at the beginning or end of the alphabet, and as having no relation to the names of the Henning classes or of the substances. The translation from the arbitrary symbol to the Henning class-symbol is as follows: I=F, J=E, K=P, L=S, M=R, and N=B.

[8] Henning, 11-17.

[9] Henning, 26-39.

### *Observers*

The *O*s who took part in this experiment were *H*, Dr. H. M. Halverson; *Ba*, Dr. Marjory Bates; and *Mo*, Miss E. F. Möller, all generally trained in introspection upon qualitative processes. They all had complete dirhinic olfaction. Another *O* was rejected because of monorhinic olfaction, due presumably to partial obstruction of one of the nasal passages. His inability to make satisfactory judgments in the preliminary experiments supports Henning's statement that dirhinic smelling is necessary for the complete appreciation of olfactory quality.

### *I. Test of the Prism by a Method of Paired Comparisons*

The first method of experimentation was a form of paired comparisons, modified to suit the implications of the Henning prism. Every stimulus was presented to the *O* with every different pair of the six standards. He was allowed to smell the three stimuli in any order and as much and as often as he desired, and was instructed to report which of the two standards the comparison stimulus resembled more closely in olfactory quality. Half-hour periods of experimentation were used to avoid excessive adaptation. The frequency of the selection of the standards was computed for each stimulus; 'equal' judgments were counted one-half for each of two standards.

Table II shows the average and m.v. of nine series, three sets of observations with each of three *O*s. It is apparent from inspection of the table that variability is great and that no absolute verification of the prism was achieved. The original data show that this variability occurred both between *O*s and between the three series of a single *O*. In fact it was the large amount of variability that determined us to combine all series for all *O*s in the hope of finding some general tendency among observations which should support Henning's theory.

In examining the table it should be borne in mind that the maximal rank under a method of paired comparisons with six paired standards is 5: the ranks for a single stimulus, unless there are tie cases, should be 5, 4, 3, 2, 1, 0. The averages, however, show no such wide scatter of ranks; the scores are reduced and brought closer together by the large variability included in the average. Thus also the table shows that the m.v.'s are large with respect to the average ranks. If the results expressed in the table were perfectly self-consistent, the m. v. in every case would be 0; if they were inconsistent with maximum perversity the m. v. could be as high as 2.5. The average m. v. for the entire table (108 cases) actually is 1.12. This means, at any rate, that *O*s accustomed to introspective observation upon qualitative processes, and presumably indisposed to objectification of odors, could nevertheless not give judgments consistent with themselves or with one another when the task consisted in relating unknown stimuli qualitatively to the corners of the supposed prism. At least we may assert that the prism is by no means so easy to establish observationally as is the color pyramid.

TABLE II

Average ranks of the six principal qualities when their stimuli are compared by a method of paired comparisons with every one of the 18 comparison stimuli. The average is the average of 3 series for each of 3 *O*s, 9 values in all; it measures the relative degree of qualitative similarity to the quality named at the top of the column. The highest possible average rank would be 5, since there are 5 comparison pairs which include any one standard. The m. v. shows the variability; the maximum m. v. would be 2.5.

| Comparison Stimulus | | STANDARD STIMULI | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F | | E | | P | | S | | R | | B | |
| No. | Class | av. | m.v. | av. | m.v. | av. | m.v. | av. | m.v. | av. | m.v. | av. | m.v. |
| 1 | F | 2.5 | 2.1 | 2.4 | 1.6 | .9 | .9 | 2.5 | .9 | 1.0 | 1.6 | .7 | .8 |
| 2 | E | 3.6 | .7 | 3.7 | 1.0 | 1.0 | .5 | 2.7 | 1.0 | 1.2 | 1.0 | 1.2 | .8 |
| 10 | P | 0.0 | 0.0 | 0.0 | 0.0 | 3.5 | 1.2 | 1.1 | 1.4 | .1 | .2 | 3.5 | 1.5 |
| 18 | S | 2.8 | 1.3 | 3.5 | .8 | .8 | 1.0 | 3.2 | 1.5 | 0.0 | 0.0 | .3 | .6 |
| 16 | R | .7 | 1.0 | 3.6 | 1.2 | 1.4 | 1.5 | 2.0 | 1.3 | 2.1 | 1.7 | .9 | 1.0 |
| 35 | R | 1.3 | 1.5 | 2.0 | 1.8 | 1.5 | 1.1 | 1.3 | 1.4 | 3.1 | 1.6 | 1.5 | 1.3 |
| 7 | B | .9 | 1.0 | 2.0 | 1.4 | 1.8 | 1.6 | 2.0 | 1.6 | 1.8 | 2.0 | .9 | .5 |
| 9 | B | 1.1 | 1.4 | .8 | 1.0 | 2.3 | 1.6 | 1.7 | 1.8 | .4 | .6 | 1.9 | 1.7 |
| 30 | FE | 3.2 | 1.2 | 4.1 | .4 | .9 | 2.2 | 3.5 | .8 | .2 | .3 | 1.1 | 1.0 |
| 33 | SR | 2.9 | 1.0 | 2.6 | 1.9 | .9 | 1.2 | 3.4 | 1.0 | .2 | 3.4 | .4 | .7 |
| 34 | SR | .8 | .9 | 2.0 | 1.4 | 1.3 | 1.2 | 2.3 | 1.9 | 3.1 | 1.6 | 2.0 | 1.5 |
| 3 | FS | 4.4 | .5 | 2.8 | 1.2 | .1 | .1 | 3.6 | 1.2 | 0.0 | 0.0 | .6 | 1.0 |
| 11 | ER | .6 | .6 | 1.6 | 1.5 | 3.7 | 1.1 | 1.8 | 1.5 | 2.2 | 1.2 | 2.4 | 1.5 |
| 5 | PB | 2.7 | 1.3 | 2.1 | 1.2 | .7 | 1.0 | 2.7 | 1.4 | 3.7 | 1.4 | .4 | .6 |
| 4 | FESR | 3.1 | .9 | 3.1 | .7 | .5 | .8 | 3.2 | .8 | 2.5 | 1.6 | .4 | .4 |
| 21 | EPRB | 3.7 | .6 | 4.8 | .2 | .4 | .6 | 2.5 | 1.1 | .2 | .3 | .6 | .8 |
| 17 | FPSB | 2.0 | 1.7 | 1.5 | 1.5 | 1.2 | 1.5 | 2.3 | 1.2 | 0.0 | 0.0 | 1.5 | 1.6 |
| 28 | FPSB | .3 | .5 | 1.2 | 1.4 | 3.2 | 1.6 | 2.4 | 1.8 | 1.0 | 1.2 | 1.5 | 1.3 |
| Av. m.v. | | | 1.01 | | 1.12 | | 1.14 | | 1.31 | | 1.09 | | 1.03 |

It is interesting to note that the rank order of variability for the principal qualitative groups is, from the most to the least consistent, F, B, R, E, P, S. The low rank of E and S is undoubtedly due to the fact that the two groups, as Henning points out,[10] are related. Most fruits are also spicy in odor, and the forked structure is apt to be added to a para-ring. Hence actually the supposedly E stimuli are not pure E and may deviate in some unpredictable manner toward S. Similarly the S's under our method of experimentation may deviate toward E, for the reason that citral, the standard for E, approximates an ES stimulus. This defect lies in the Henning theory; we could not with assurance choose a better standard for E. Consistency is high for F and R, for these groups are more definitely establishable. Introspection shows F and R to be quite different in quality, and they are never confused as are E and S. In general, the PB portion of the prism is unsatisfactory because too few stimuli can be found adequately to represent it, and the positions of P and B in the rank order given above are less significant than those for the other four groups.

The variabilty, as shown in Table II, seems not to be due to lack of practice within the limits of our experiment, for the third series shows just as little agreement among *O*s as did the first series.

In the face of such great variability the natural resort is to statistical procedure. We have therefore correlated the theoretical ranks, which would obtain if the three sides of the Henning prism are squares, with the observed ranks.

It will be seen that the theoretical ranks are somewhat different for simplex, duplex and multiplex stimuli. For a simplex stimulus the quality for the corner at which it lies should rank 5; the three corners, equally distant from this corner by the side of a square, should each rank 3, and the two remaining corners, distant by the diagonal of the square, should rank 0.5 each. With a duplex stimulus the two adjacent corners should rank 4.5 each, and the four remaining corners 1.5 each. With a quadruplex stimulus the four equidistant corners should rank 3.5 each; and the two remaining corners should receive no score at all, for the reason that the prism is hollow and there is no single continuum leading to the opposite edge whereby a judgment of similarity can be made. Theoretically the ideal series of ranks would be:

For a simplex stimulus: 5, 3, 3, 3, 0.5, 0.5.
For a duplex stimulus: 4.5, 4.5, 1.5, 1.5, 1.5, 1.5.
For a quadruplex stimulus: 3.5, 3.5, 3.5, 3.5, 0, 0.

The coefficients of correlation (products-moments) between these theoretical and the observed values are as follows:

| Standard Stimulus: | F | E | P | S | R | B |
|---|---|---|---|---|---|---|
| $r=$ | .360 | .432 | .309 | .334 | .435 | .119 |
| $P.E._r=$ | .138 | .129 | .144 | .141 | .129 | .157 |

The average correlation is $r=.331$. The low value for B ($r=.119$) is explained by the fact that a potentially B stimulus tended to yield to all the other five groups in judged similarity; *cf.* Table II.

[10]Henning, 295.

In general, then, we may say that we succeeded in verifying the Henning prism only to the extent of agreement that is indicated by a coefficient of correlation of 30% to 40%. We shall see later some of the difficulties which accounted for this rather unexpected failure.

## *II. Test of the FESR Face by a Method of Qualitative Placement*

Since the PB line and its adjacent faces could be only incompletely filled in, we decided to confine our further experimentation to the FESR face, for which numerous representatives were available.

The *O*s were trained to make judgments of qualitative relationship in the following manner. A card 15 inches on a side was divided into 25 three-inch squares. Twenty-five small colored squares about one inch on a side, all between red and blue and of various tints, a systematic selection from the Milton-Bradley series, were cut from colored papers. A light red, a dark red, a light blue and a dark blue were placed at the four corners of the square, thus indicating a red-blue bidimensional qualitative continuum in which the hue varied in one dimension and the tint in the other. The *O*s were asked to place, separately, each one of the other 21 colors in the continuum in qualitative relationship to the four standards at the corners. They found no difficulty in performing this task accurately.

These conditions were now duplicated for the FESR face of Henning's prism. The F, E, S, and R standards were substituted for the colors at the corners of the large square, and the *O*s were asked to place singly on the square every one of the 11 olfactory stimuli of the FESR group in qualitative relation to the standards. A series consisted of the placement of each of the 11 stimuli. Ten such series were taken, each at a separate session. The results are shown in Table III and in Figg. 1-3. In the figures the circles show the position of average placement for such stimuli as the *O* was able to place as many as five times out of 10 trials, and the lines run from the positions of actual placement to the average.

All the *O*s experienced difficulty in making the placements, a difficulty which they did not have in the preliminary trial with the colors. They responded differently, however. *Mo* accepted the instruction and managed every time to find a place for every stimulus; *Ba* found a place for only three of the 11 stimuli five or more times. *Ba* was never well satisfied with her judgments and worked under protest. No stimulus did she place more than seven times out of 10; every stimulus she placed at least once. Altogether she made 36 placements out of a possible 110. *H* placed eight stimuli five or more times and made 76 placements out of 110.

TABLE III

Average placement of 11 stimuli by 3 *Os* (*Ba*, *H*, *Mo*) in the FESR face of the prism. $x$ = horizontal displacement from the FS edge toward the ER edge; $y$ = vertical displacement from the SR edge towards the FE edge. All figures are in units defined by length of side = 10 units, *i. e.*, the maximal horizontal or vertical displacement is 10 and the maximal diagonal displacement is 14.14. Average displacement is the average deviation of the placements from the average position shown in Figg. 1-3. Ten trials for each stimulus were given each *O*, but *H* and *Ba* did not always succeed in making a placement within the square. When the number of placements is less than 5, no averages have been computed.

| Comparison Stimulus | | No. Cases | | | Average $x$ | | | Average $y$ | | | Average Displacement | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Class | *Ba* | *H* | *Mo* | *Ba* | *H* | *Mo* | *Ba* | *H* | *Mo* | *Ba* | *H* | *Mo* |
| 1 | F | 6 | 10 | 10 | 2.50 | 8.92 | 3.25 | 6.66 | 9.91 | 7.25 | 2.83 | 1.27 | 2.23 |
| 2 | E | 1 | 10 | 10 | — | 7.25 | 5.50 | — | 8.25 | 5.50 | — | 2.71 | 2.13 |
| 3 | FS | 3 | 4 | 10 | — | — | 3.00 | — | — | 8.50 | — | — | 1.79 |
| 4 | FESR | 3 | 10 | 10 | — | 5.75 | 4.75 | — | 4.25 | 4.66 | — | 1.79 | 2.04 |
| 11 | ER | 1 | 1 | 10 | — | — | 7.00 | — | — | 4.25 | — | — | 2.21 |
| 16 | R | 7 | 0 | 10 | 3.58 | — | 4.75 | 4.25 | — | 8.00 | 3.07 | — | 1.50 |
| 18 | S | 2 | 9 | 10 | — | 0.58 | 3.50 | — | 3.00 | 4.25 | — | 1.52 | 2.17 |
| 30 | FE | 3 | 10 | 10 | — | 3.75 | 5.25 | — | 4.75 | 5.05 | — | 2.71 | 1.06 |
| 33 | SR | 2 | 5 | 10 | — | 0.50 | 4.25 | — | 4.00 | 4.50 | — | 1.54 | 2.25 |
| 34 | SR | 5 | 9 | 10 | 6.50 | 10.00 | 7.75 | 2.50 | 3.33 | 6.25 | 2.46 | 1.56 | 1.38 |
| 35 | R | 3 | 8 | 10 | — | 10.00 | 6.00 | — | 1.58 | 5.50 | — | 1.14 | 3.06 |
| | | | | | | | | Average | | | 2.82 | 1.70 | 1.98 |

The figures and Table III show that the *Os* varied considerably. *H* was the most consistent *O*: on the average his displacement of a stimulus from its average position was 1.70, where the length of the side of the square is 10. *Mo* is the next most consistent, with an average displacement of 1.98. Her greater variability may be due to her acceptance of the instruction in such a way as to lead her to place all the stimuli. *Ba*, however, who refused to make placements because of her lack of assurance, is still less consistent for the three bottles which she placed 5, 6, and 7 times; her average displacement is 2.82.

We took protocols from all the *Os* concerning their procedure in making placements. *H* and *Mo* both reported that they began by selecting the one of the four standards that most resembled the comparison stimulus. Then they found the standard or standards which next most resembled the comparison stimulus, and placed it with respect to all the standards that had come under consideration, correcting the placement with respect to the remaining standard or standards later. *Mo*'s procedure was more fixed than *H*'s. After deciding upon the first standard, she always went on to place the comparison stimulus in relation to the two adjacent standards, ending with a final correction which took account of the standard diagonally opposite. *Ba* gave little account of method, since she was more concerned with the rejection of stimuli than with their placement.

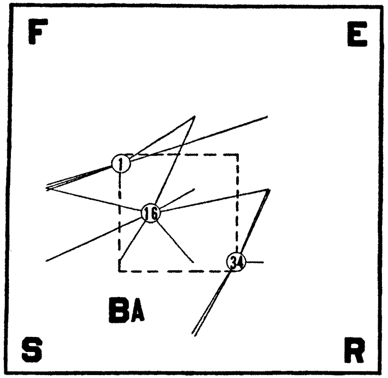


FIG. 1

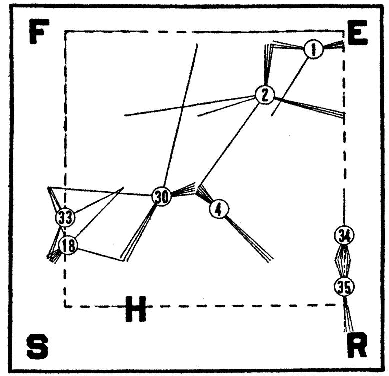


FIG. 2

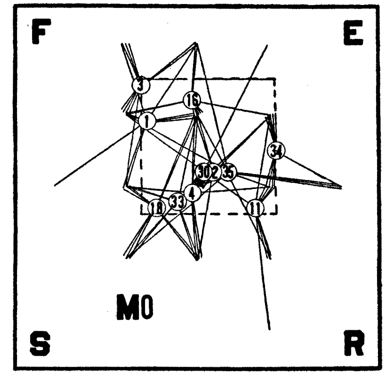


FIG. 3

FIGS. 1-3. Average position and displacements, indicated by radial lines, of the stimuli which *Ba*, *H*, and *Mo* placed in the FESR face of the prism five or more times out of ten trials. See Tables I and III. The dotted lines indicate the "reduced squares" used in computing the average deviation from theory. The key to the stimulus numbers and their classification is as follows:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | Ionone | 4 | FESR | Menthol | 18 | S | Nutmeg | 34 | SR | Myrtenol |
| 2 | E | Acetic ether | 11 | ER | Xylene | 30 | FE | Geraniol | 35 | R | Pinene |
| 3 | FS | Vanillin | 16 | R | Frankincense | 33 | SR | Allspice | | | |

All three *Os* had a great deal to say of the dfficulty of the task. Resemblance was not apparent, as with the colors, and the odors sometimes seemed complex.

After the completion of the main series with the FESR face of the prism, we conducted a supplementary series in which each *O* was asked to place every stimulus once and to give a full account of the method of placement.

These supplementary protocols accorded in general method of placement with the accounts given during the main series mentioned above. In addition, however, they brought out certain typical difficulties of the task which bear directly on the nature of the prism. These difficulties may be summarized as follows.

(1) Occasionally a stimulus is reported as resembling none of the four standards and is placed off the square. (No. 33, allspice, for *Ba*; no. 35, pinene, for *Mo*.)

(2) Frequently stimuli resemble a standard and some other unknown quality that does not lie in the square. Such qualities belong to some extension of the continuum beyond the square, and are properly placed off the square. (No. 3, vanillin, for *Ba* and *H*; no. 4, menthol, for *Ba*; no. 11, xylene, for *H*; no. 16, frankincense, for *H*; no. 30, geraniol, for *Ba*; no. 33, allspice, for *H* and *Mo*; no. 35, pinene, for *Ba* and *H*.)

(3) Occasionally a triplex quality is reported as about equally similar to three standards but not resembling the fourth. Strictly speaking, such a quality can not be placed in the square, since its placement with respect to three corners immediately implies a relationship to the fourth. As a matter of fact *Mo* placed such stimuli near the center of the square in spite of the incorrect implication. (No. 2, acetic ether, for *Mo*; no. 30, geraniol, for *Mo*.)

(4) Sometimes there is reported a duplex quality resembilng diagonally opposite standards. Such a quality also ought not to be placed, since its location near the midpoint of a diagonal puts it also at the midpoint of the other diagonal and renders it a quadruplex quality. In three of these cases the stimuli were actually, though thus incorrectly, placed near the middle of the square; in one case *Ba* refused to make a placement because of the incompatibility involved. (No. 1, ionone, reported ES by *Ba* and not placed; no. 4, menthol, reported FR by *H*, although Henning calls it ES; no. 13, nutmeg, reported ES by *Mo*; no. 30, geraniol, reported ES by *H*.) It is to be recalled that Henning especially notes the existence of the duplex ES, although he does not explain the inconsistency that it implies in the prism.

It will be noted in the figures that the placements tend toward the center of the square. Various factors may account for this result. (1) Since the placements were bounded by the edges of the square, chance placement would tend toward the middle. (2) The odors were noted for their dissimilarity from the standards. Even on Henning's theory, two F's, for example, may be very different sensations. Since the four standards only were given, the tendency must have been to place the stimuli well away from the corners. (3) It is possible that the method of placement which *Mo* employed led her to put most of her comparison stimuli near the center. By invariably bringing the stimuli into relation with three standards she tended to favor placements in the positions of multiplex stimuli and to discourage placements as duplex and simplex odors. In examining

the figures, then, we must take into account the tendency toward the center and attend more to the relative placement than to the actual position in the given FESR square.

We may now examine the results for each of the stimuli separately, noting the stimulus number, the substance, the Henning classification, and the *O*s who placed it five or more times.

1. Ionone. F. *Ba, H, Mo.* Chemically it should be a good F. *Ba* and *Mo* place it toward F in their constellations, but *H* consistently approximates it to E.

30. Geraniol. FE. *H, Mo.* Henning classifies it as FE. Chemically however (see above) it should be ES, which under the logic of the square continuum should become FESR. Both *O*s localize it in the center, as its chemistry on Henning's assumptions would require.

2. Acetic ether. E. *H, Mo.* Chemically also it should be E. *H* places it near E and *Mo* places it near the center; *H*'s greatest deviations are, however, toward the center and *Mo*'s toward E.

11. Xylene. ER. *Mo.* Supposedly ER, but does not accord with the chemical theory (see above). *Mo* places it consistently near the ER side of her constellation.

16. Frankincense. R. *Ba, Mo. Ba* makes it central and *Mo* places it toward the FE side. It does not seem to be R. It was, however, a weak stimulus and less satisfactory on this account than others.

35. Pinene. R. *H, Mo.* Also belongs chemically at R. *H* places it at R with great consistency, but *Mo* places it near the center.

33. Allspice. SR. *H, Mo.* We assumed that it should be SR from Henning's account of this line. It is probably to be considered an S since it is close to no. 18.

34. Myrtenol. SR. *Ba, H, Mo.* According to Henning this is also chemically SR, although we have not been able to verify his formula. *H*, however, makes it definitely ER; *Mo* locates it toward ER; and *Ba* puts it as near ER as SR.

18. Nutmeg. S. *H, Mo.* Both *O*s place it toward the S corner.

3. Vanillin. FS. *Mo.* She makes it F rather than FS.

4. Menthol. FESR. *H, Mo.* According to Henning it is a duplex ES; according to its chemistry it should be triplex FES; according to the logic of the square continuum it would have to be FESR if it were ES. Both *O*s conform to Henning's statement by placing it near the center. It does not seem to tend toward the F side, however.

It is difficult to make any general statement of the agreement of these results with Henning's theory. So many factors enter in, and agreement can occur or fail in so many ways. It is, however, possible to measure the deviation of the average position from the theoretical place for each stimulus, but in so doing we encounter the difficulty that arises from the tendency of all *O*s to group the placements in the center of the square. We have shown the possible causes for this tendency, and it does not seem fair to include it as a factor in any measure of the relationship between observation and theory. Accordingly we undertook to correct for it by redrawing the squares of Figg. 1-3 so that they would just include all the average points (see dotted squares in the figures) and computing the average deviation, for each *O*, of the average placement from the theoretical position. If the side of the reduced square be taken as 10 units,

then these average displacements in terms of such units are as follows: for *Ba*, 4.85; for *H*, 4.23; for *Mo*, 5.35. In other words, the discrepancy between theory and actual placement is on the average about one-half the length of a side of the square for every *O*. It does not appear, therefore, that agreement with theory is very much greater in these series with the FESR face than the correlation of 30-40% that we found before for the entire prism.

### *Logical and Factual Inadequacies of Henning's Theory*

1.The prismatic theory of odor may be said in general still to be insufficiently worked out. For certain portions of the prism Henning gives numerous examples that should enable one more or less readily to reconstruct the qualitative system in experience, but in other portions a definite knowledge of the necessary stimuli is still lacking.

Thus a discussion of the internal constitution of the triangular bases of the prism is entirely lacking; presumably triplex odors should lie here.

Moreover, stimuli for the two faces which include the PB line are insufficient. Henning himself noted the difficulty of filling out the PB line, but the adjacent faces are also inadequately represented. We obtained no satisfactory stimuli for the FP, EP, SB, and RB lines, and Henning gives no definite chemical substances that belong to these positions. With respect to the quadruplex odors belonging to these faces, we find that FPSB can be adequately represented by the celery lactones, the onion esters, and the parsley phenols, of which apiol is an example; but the EPRB face has only the indefinite odor of grapefruit to represent it.

Another insufficiency appears at the E corner. Most of the fruity odors, which belong to this group, are actually similar to S, so that they are not proper representatives of E. Henning's own statement, the chemistry of these odors according to Henning's theory, and our own qualitative findings accord here.

2. Henning's chemical theory also presents insufficiencies in the FPSB and EPRB faces. It is not made clear how chemical intermediates between P and B, on the one hand, and F, E, S, and R, on the other, can occur or what the nature of an intermediate would be. The lack of examples makes it impossible to deduce generalizations. There is no apparent chemical reason why apiol, for example, a complex penta-substitution product, should be a quadruplex FPSB stimulus.

3. The question arises whether the FESR face is properly a square. The close relationship of the E and S corners suggests that the ES diagonal may be shorter than the FR diagonal. It may be, however, that the face is theoretically a square and

that the best practicable stimuli for E are ES, with pure E lying diagonally out beyond, very much as the corners of the theoretical color triangle lie beyond the actual spectral triangle enclosed within it.

4. The existence of triplex odors in a face seems to constitute a logical difficulty for the prismatic theory, in which the odors on a line should be duplex and the odors in a face quadruplex. Henning, however, seems to admit the existence of triplex odors (*e. g.*, thymol, p. 299, and dehydrocamphylcarbinol. p. 299), and our *O*s also report triplex odors which they have for this reason difficulty in placing upon the square (*e. g.*, acetic ether, FES, and geraniol, FER, for *Mo*).

5. An even more fundamental logical difficulty with the prism lies in the fact that there seem to be duplex odors for the diagonally opposite corners. Henning especially notes the usualness of the ES odors, and our observer *H* reported menthol as FR. If the prism is to stand, it is absolutely necessary that ES stimuli should also be FR and conversely, for only quadruplex odors could lie at the center of the diagonals. The trouble seems to be with the prism and not with Henning's observations; our *O*s frequently reported ES odors.

The solution may lie in some other geometrical construction If a solid tetrahedron were substituted for the FESR face, it would be possible to have all duplex, triplex and quadruplex odors that could lie between these four corners. If the other faces were similar, we might have a hollow hyper-solid with solid tetrahedrons as its sides. There is no reason why mental continua should occur only under Euclidian limitations.

6. This same difficulty with the ES odors appears also on the side of the stimulus. ES stimuli are normal, for the forked structure is found attached to the para-substitution. If Henning's theory were to be taken strictly there should be no such stimuli nor combinations of inner with ortho-rings (FR); the combination of one pair of these characteristics should necessitate the addition of the other pair. Geraniol, citral, and citronellol all violate the logic of the prism, in that they combine para-substitution with a fork without further additions.

7. Similarly, there should be no chemically triplex stimuli, since the position of the odor of such a stimulus in a face implies a similarity to the fourth corner. The case of menthol illustrates both this difficulty and the one preceding. Henning describes menthol as ES, a duplex odor, and *H* called it duplex FR. Chemically, it combines the ortho- and para-substitution with a forked structure, and should be a triplex stimulus, FES. Logically, however, since it lies in a face, it should be a quadruplex FESR.

8. A general difficulty with the Henning theory lies in the fact that it seeks to explain a qualitative continuum by correlation with discrete chemical changes. From S to F, for example, there is only one possible chemical intermediate, the asymmetrical ring that combines the para- and ortho-substitution, whereas there are apparently many qualities, with perhaps the possibility of continuous qualitative change.

9. In basing the FESR face on the benzine ring, it must be noted that Henning is interpreting the nature of the E stimuli rather broadly. These molecules, bearing a forked structure, are open chains and not rings. Their relation to the benzine group lies only in the fact that they may readily condense into rings.

The molecules of the P stimuli Henning describes as disrupted rings (*Aufsplitterung der Ringe*), although they are open chains without relation to the cyclic molecules. It would seem that the emphasis should be placed, as we have had occasion to do above, upon the nature of the osmophores and not upon the molecular structure.

10. The chemical theory does not permit rigorous prediction of quality, if Henning's qualitative descriptions are accepted. Among our own stimuli the following inconsistencies appeared. Citral, described as E by Henning, should be ES on the basis of its molecular structure. Citronellol and geraniol Henning seems to characterize as FE: their structure demands that they be ES: they include no ortho-substitution products that would make them F. Menthol, as we have seen, is called ES by Henning, when chemically it is FES. Amyl alcohol is an open chain with a fork and belongs chemically at E, but it is one of the few examples besides the animal foetors that Henning places on the PB line. Xylene is a disubstitution product and might be expected to be F or S; it is placed by Henning on the ER line. Carbon disulphide has a proper formula to represent the P corner, but its odor is said to be due to impurities.

11. Criticism of the chemical theory has necessarily been based on the internal consistency of Henning's own presentation. Criticism of the prismatic theory of olfactory quality is the main purpose of the present study. In it we have shown by a method of paired comparisons, involving stimuli that should represent the entire prism, that we could obtain only 30-40% correlation between the qualitative relationships as stated by Henning and as observed by our *O*s. We have also shown that, in placing stimuli within the FESR face, our *O*s, even when allowance is made for their tendency to place all unknowns toward the center of the square, deviated from Henning's placement by an amount equal to about one-half the side of the square. Both these results, however, issue from data

where individual variation is large, so that it may be argued that our failure better to verify the theory may be due to some fundamental difficulty in observing the qualitative relationships implied. The existence of such difficulties was apparent in certain series where the *O*s found some unknowns related to qualities not represented in the system and (rarely) to no qualities in the system at all.

It is the opinion of the writer that Henning's theories represent an advance, a first approximation to the truth. They can not, however, be applied rigorously, nor does the smell prism represent so definitely understood a system of qualities as does the color pyramid.

### Note on Dimmick's Experiment

Since the acceptance of this manuscript for publication Dimmick has published "A Note on Henning's Smell Series."[10] Our proof sheets do not afford an adequate opportunity for the comparison of Dimmick's experiment with ours, but subsequent discussion may be avoided if certain divergences between the two experiments are noted here.

Both experiments are prejudiced to some extent by necessary methodical presuppositions. Dimmick assumed the validity of the prismatic theory of quality and sought to determine the best or most constant representatives of the theory; his study can not constitute a critique of the theory, but has the advantage of determining the best principal odors under the theory. Our study, on the other hand, raises the question of the validity and degree of applicability of the prismatic theory, but necessarily had to assume specific stimuli as representative of the principal classes of odor.

Our effort to obtain standards of definite chemical composition renders comparison difficult. Dimmick justifies our F standard (oil of jasmine), and raises a presumption in favor of the appropriateness of our E and R standards (if citrol and eucalyptol can be regarded as equivalent stimuli to lemon oil and eucalyptus oil). We are unable to come in contact with Dimmick's experiment at all with respect to the S and P corners. Pyridine, our standard for B, Dimmick places on the PB line.

There are only seven stimuli identical to the two experiments, and six more which are similar, as, *e.g.*, anisol and anise oil.

There seem to be a few instances (we have noted six) where Dimmick and we differ in the interpretation of Henning's specification of a stimulus. These discrepancies, however, are, with one exception, never greater than the difference between a corner and a line leading to that corner; and in these matters Henning is remarkably difficult of interpretation.

In general we note that the greatest difficulty in the test of the theory consists in the difficulty of establishing in advance the principal classes of odors to which the unknowns are to be referred in the qualitative schema. Given R, Y, G, B, Wh, and Bk, it is easy enough to demonstrate the validity of the color pyramid, but there seems to be as yet, in spite of these two experiments, no similarly easy mode of determining the principal olfactory points of reference. *Hauptrot,* for example, may be difficult of exact determination, but the general concept of "redness" can be easily be given to an *O*, much more readily than can the concept of "fragrance" or a *hauptblumig* odor. Moreover, it would seem that the various F's are very much more different from one another than is any group of colors all of which could be called "red."

[10]F. L. Dimmick, this Journal, 1922, 33, 423-425.